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(54) Antenna comprising a closed loop and a ground plane

(57) An antenna comprises a closed loop 1 spaced above a ground plane 2 with a transmission line 5 coupled to the loop 1 at spaced connection points 10 and 11. The loop 1 may be arranged in a plane parallel to the ground plane 2 and one or more dielectric layers, possibly of different permeabilities, may be between the loop 1 and the ground plane 2. The loop 1 may be formed on a printed circuit board and may have a diameter of 8cm or less and may include one or more extra conductive portions 11, 15, 16 and 19 joined to it to alter its characteristics. The antenna may be formed as a rigid or flexible structure and may be used for mobile telephones, mounted on a vehicle windscreen or used in an antenna array arrangement.

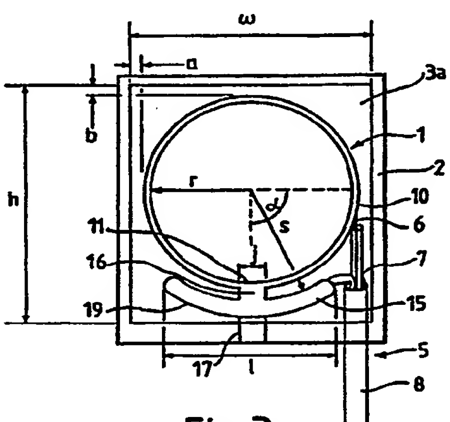

Fig.3.

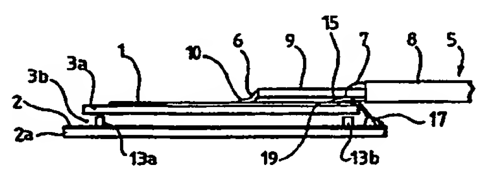

Fig.4.

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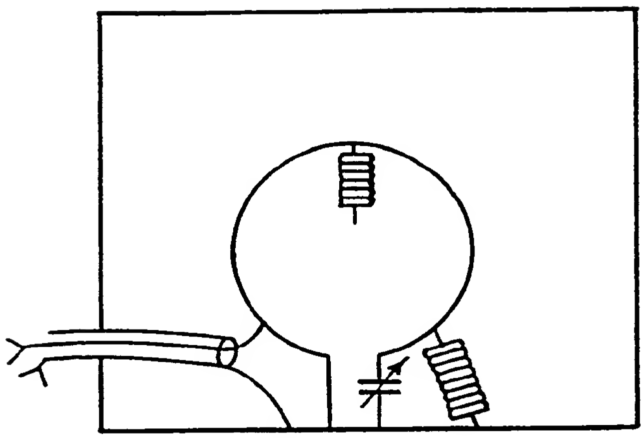

Fig.1a.

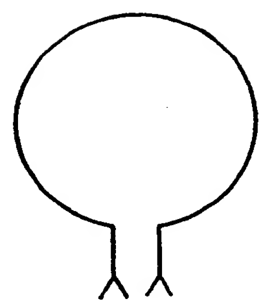

Fig.1b.

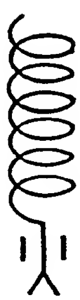

Fig.1c.

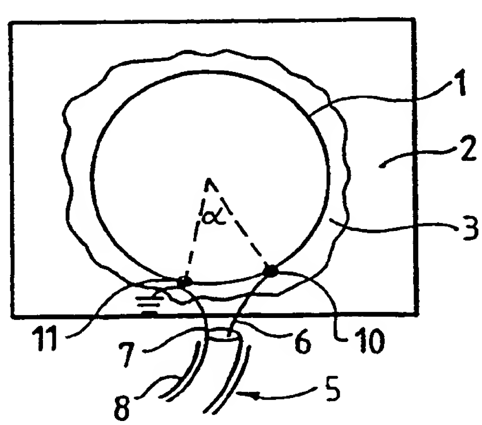

Fig.2.

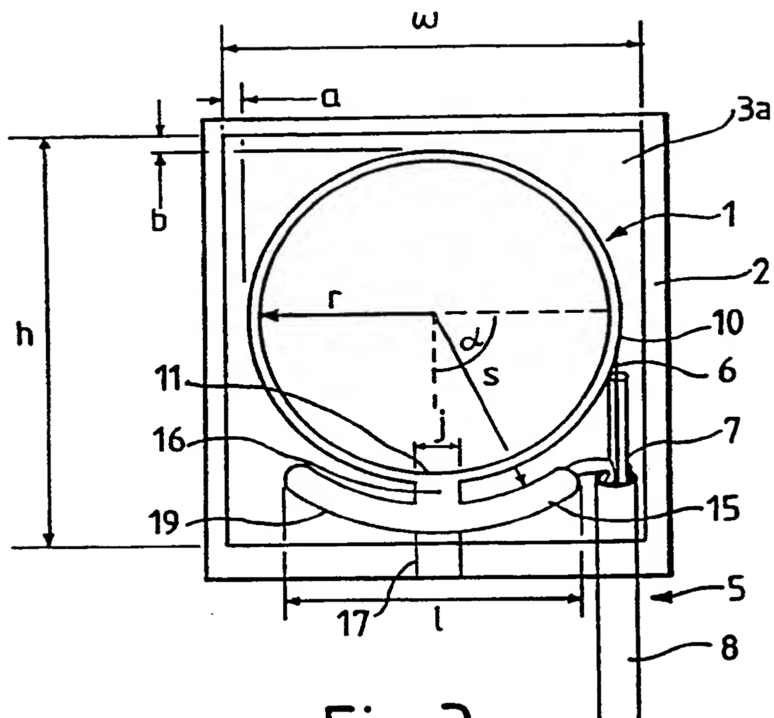
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Fig.3.

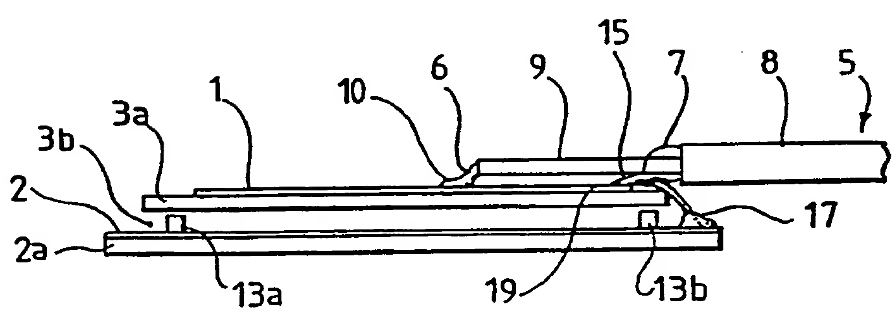
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Fig.4.

Fig.5a.

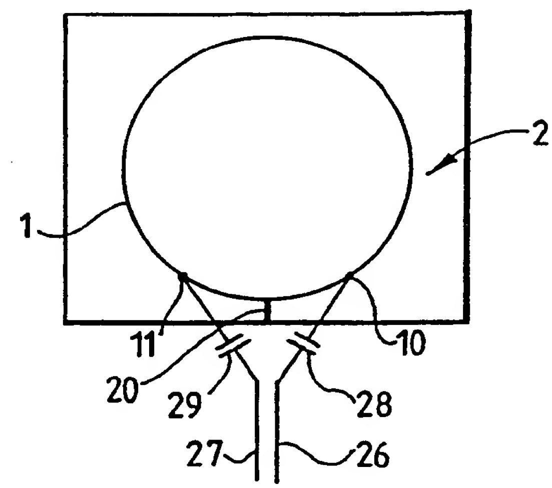


Fig.5b.

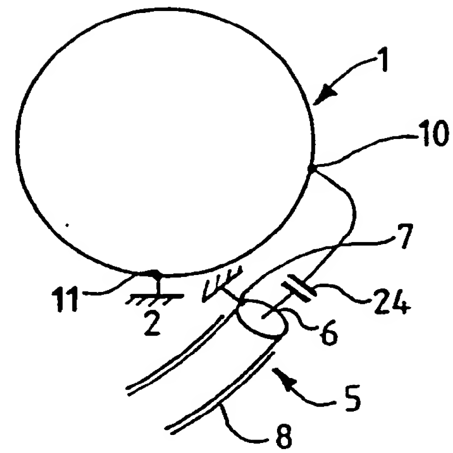


Fig.5c.

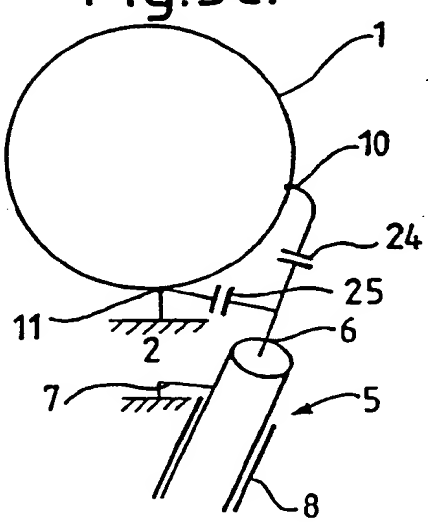
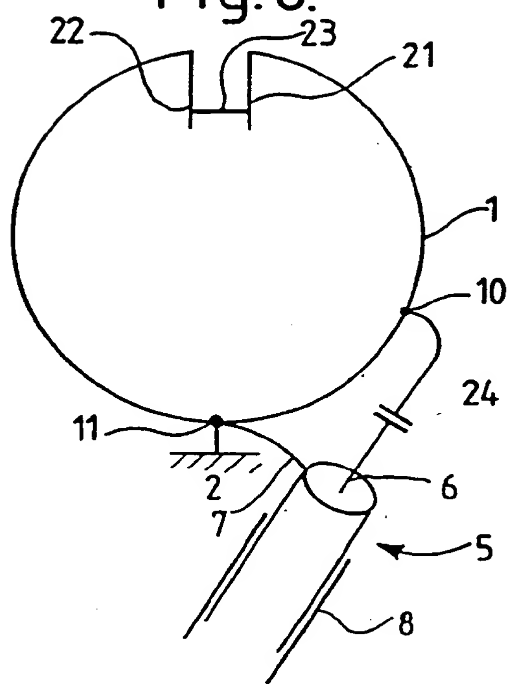


Fig.6.



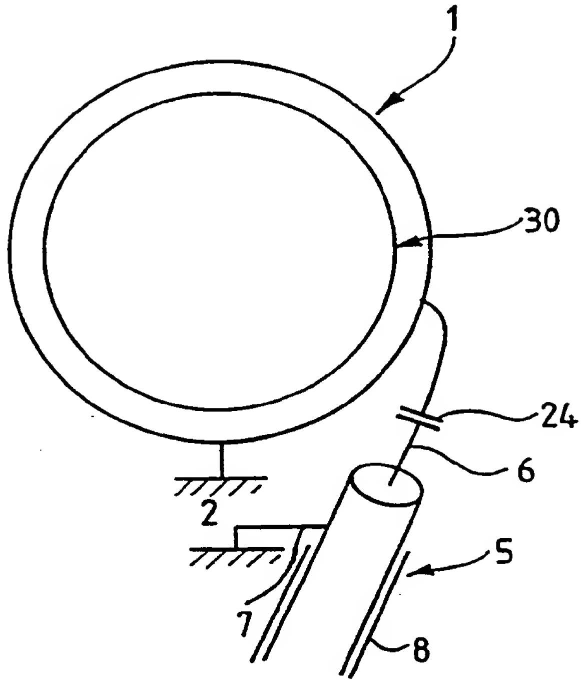


Fig.7a.

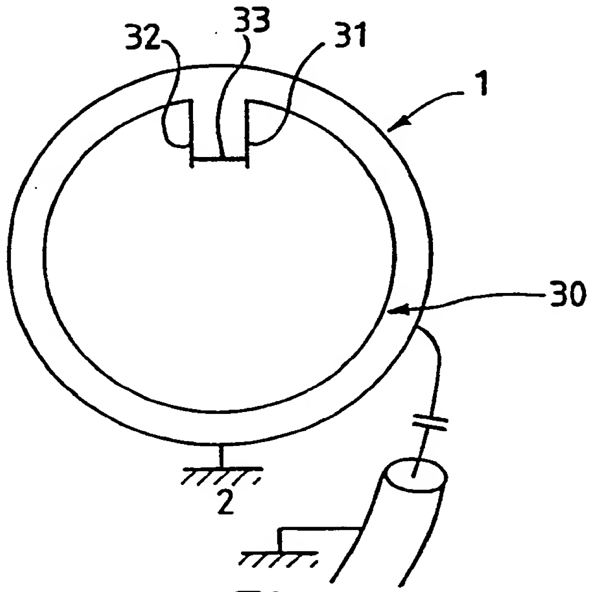


Fig.7b.

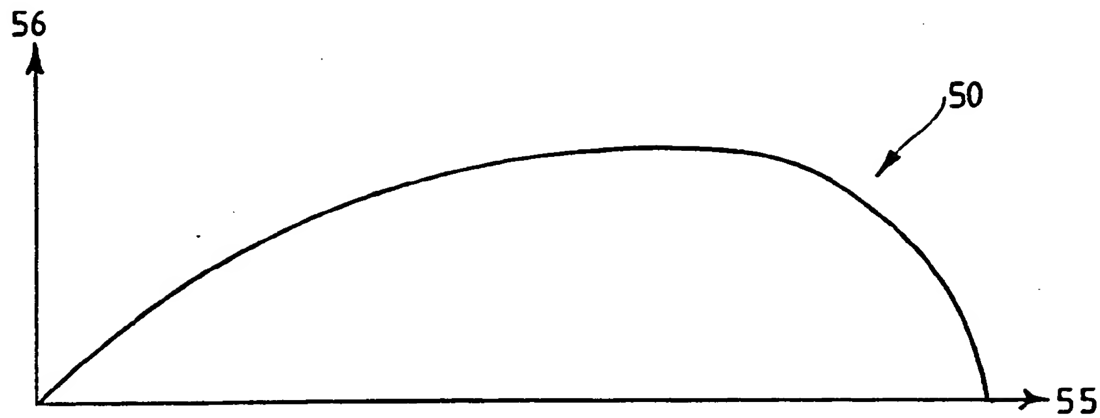


Fig.8a.

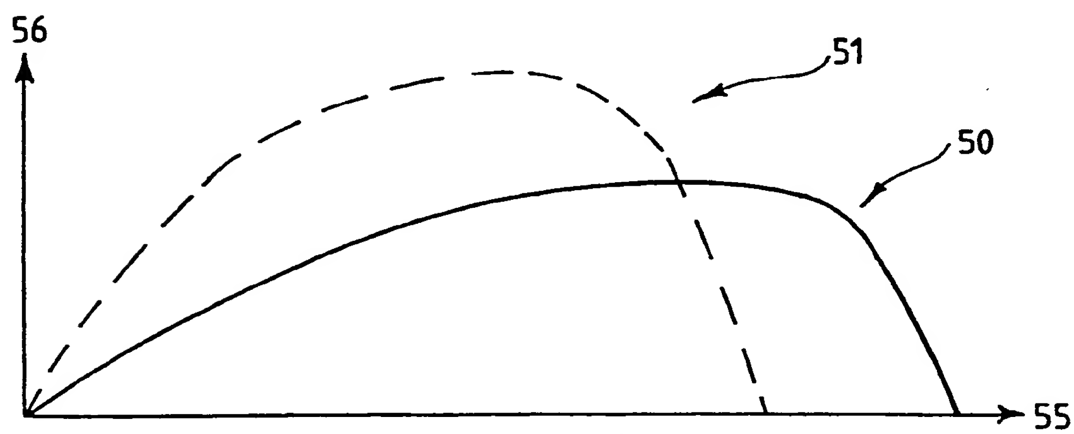


Fig.8b.

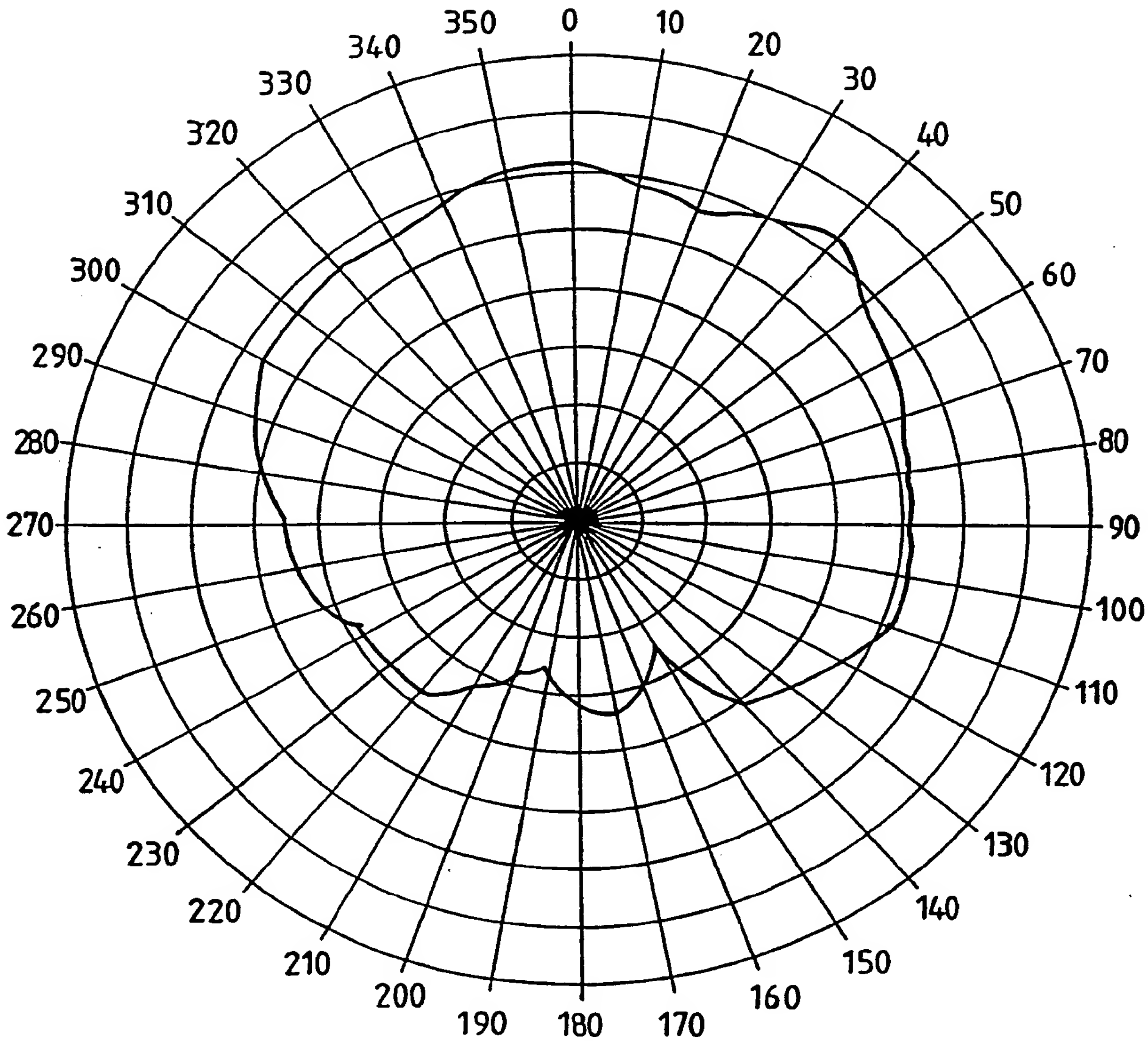

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Fig.9a.

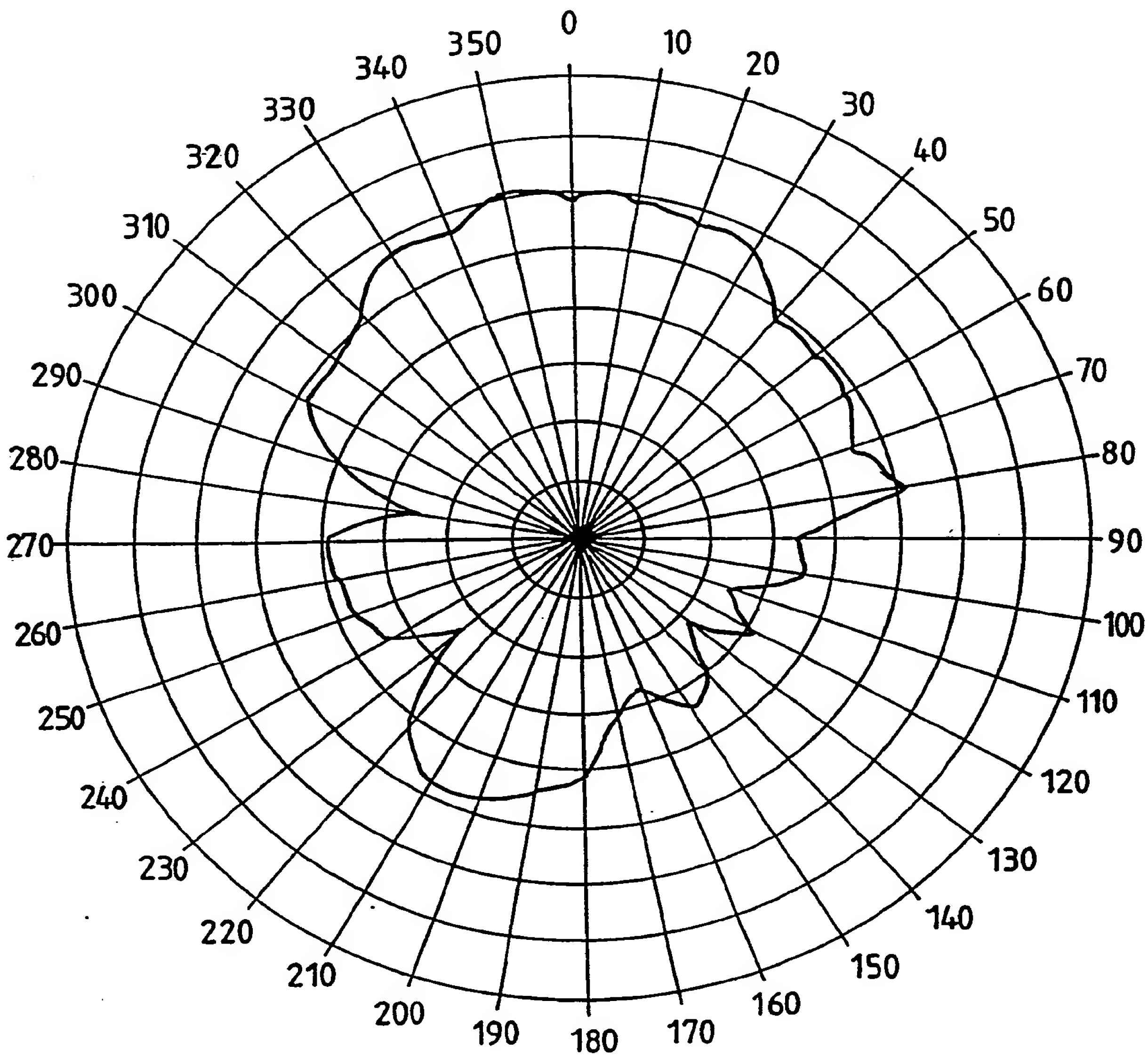
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Fig.9b.

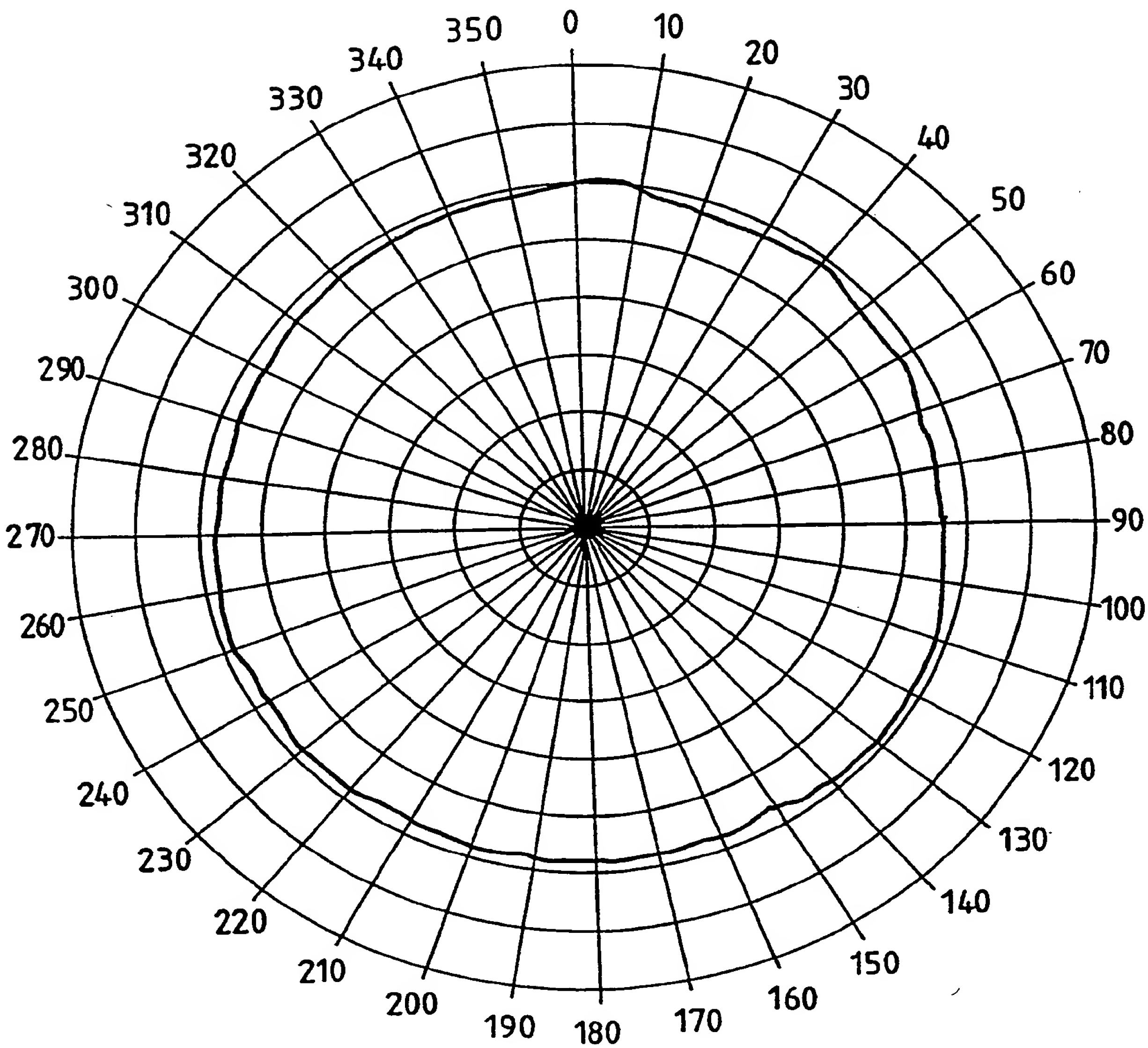
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Fig.10a.

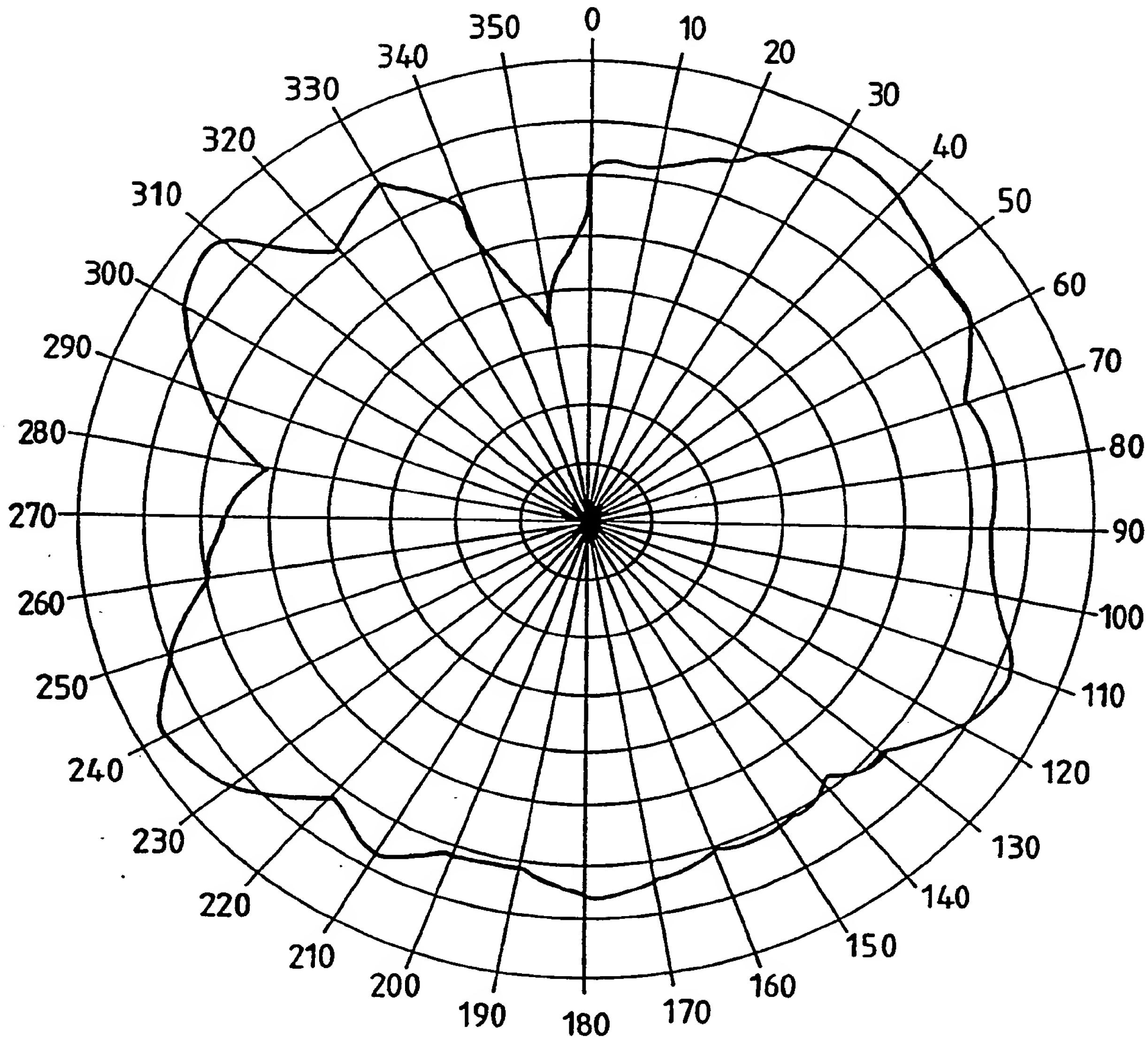
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Fig.10b.

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ANTENNA DEVICE AND MOBILE TELEPHONE

The present invention relates to an antenna device for use in radio frequency communication. The antenna device of the present invention is particularly suitable for use at higher frequencies, such as those employed in mobile telephones, but may be used for lower frequencies as well. The present invention also relates to a mobile telephone incorporating an improved antenna.

In the prior art, a large variety of antenna systems have been employed, depending on the frequency employed, and the physical constraints on the antenna. For low frequencies, a long wire or dipole is often used.

There is also known, for use at low frequencies, an open-loop aerial, as depicted in Fig. 1a in which an open loop of wire is spaced from a ground plane by insulators, with one end being capacitively tuned to ground, and the signal fed at a tap close to the other end, which is shorted to ground. The circumference of the loop is approximately one quarter of the wavelength of the signal to be transmitted or received.

This suffers from the disadvantage that complex tuning is required to achieve a desired resonant frequency and impedance. Furthermore the antenna is bulky due to the large insulators required to space the antenna from the ground, to prevent breakdown of the air. It has been difficult to use this antenna at frequencies above 100 MHz requiring specialized

manufacturing techniques.

Another type of antenna, used for higher frequencies, such as in portable television receivers, is a simple open-loop aerial, where the loop circumference is approximately equal to the wavelength of the signal. In this case, there is no ground plane and the loop is normally mounted with its plane vertical. This is illustrated in Fig. 1b.

For use in mobile telephones, where the frequencies are approximately 900 MHz, and the aerial must be compact, a short rubber rod with a helical winding, such as illustrated in Fig. 1c, is generally used. Because it is necessary to make such an aerial compact, the aerial usually cannot be an optimum length for the wavelength used, and is therefore inefficient. Furthermore, the aerial radiates uniformly, so in a mobile telephone an appreciable amount of energy goes directly into the user.

The present invention seeks to provide a novel antenna, which can be made compact, can be coupled to a variety of transmission lines, and is generally more efficient than a conventional antenna of the same dimensions.

The present invention provides an antenna device comprising an electrically conductive closed loop spaced above a ground plane, with two connection points spaced around the loop for connection to a radio-frequency transmitter or receiver.

Preferably the circumference of the loop is between one half and three quarters of the desired

signal wavelength. Typically, the circumference is set at about five eighths of the wavelength, or less. However, this may be reduced to about a third or less of the free-space wavelength if a dielectric is positioned between the loop and ground plane. In addition, the size depends on the arrangement used for matching the antenna to a transmission line.

The shape of the loop is preferably substantially circular, but other shapes such as squares, hexagons, triangles etc. may be employed. Furthermore, the shape may be chosen to achieve a desired radiation pattern, e.g. by using irregular shapes.

The loop is preferably planar, with the plane of the loop substantially parallel to the ground plane.

When the transmission line is connected directly to the loop, the two connection points are preferably spaced between 2.5° and 90° apart (when the loop is a circle), typically 35° to 50°, or about 45°. In some circumstances, however, the spacing can be 120° or larger, depending on the arrangement for matching the transmission line to the loop.

An advantage of the present invention is that the impedance and resonant frequency of the antenna can be adjusted by varying the spacing of the loop from the ground plane, and/or by altering the dielectric material and/or by changing the circumference of the loop. This may simplify coupling to a transmission line. The impedance and/or resonant frequency and/or the bandwidth and/or the efficiency can be adjusted by varying the position of the connection points.

The space between the loop and the ground plane could be filled with air, but preferably includes a dielectric having a higher relative permittivity, and higher breakdown voltage than air. If a dielectric is used, the overall dimensions of the antenna may be reduced relative to the dimensions of an antenna with an air dielectric. The reduction in size is dependent on several factors including the velocity factor (relative permittivity) of the dielectric and the dimensions of the antenna.

More preferably, the space between loop and the ground plane includes two dielectrics of differing permittivities, and preferably the dielectric with the higher permittivity is closer to the loop. The dielectric adjacent the loop preferably has a relative permittivity of at least 2, and may be glass-fibre board having a permittivity of approximately 5.4. The dielectric adjacent the ground plane can be air, which is found to give good radiation efficiency. Other dielectrics, such as PTFE or polyamide, having low relative permittivities (preferably less than about 2) may be used.

The overall spacing between the loop and the ground plane can vary, but is preferably made quite small. For use at frequencies from about 800 MHz-1200 MHz, it is preferably less than 1 cm, more preferably less than 5 mm, preferably about 2 to 3.5 mm, so that a compact aerial can be formed.

The antenna device may be formed on a double-sided printed circuit board, with one side forming the

ground plane, the loop being formed on the other side, and the board serving as the dielectric. In this way, a very compact and easy to manufacture antenna device may be formed.

More advantageously, the antenna may comprise two pieces of printed circuit board, each comprising a substrate having an upper conductive layer maintained spaced apart and substantially parallel, the upper conductive layer of the uppermost board forming the loop, and the upper conductive layer of the lower printed circuit board forming the ground plane. With this arrangement, the space between the loop and the ground plane includes the substrate of the uppermost board and the air between the boards. This arrangement is found to give good radiation efficiency.

Preferably, said two printed circuit boards are maintained spaced apart by at least one spacer. This arrangement allows parameters, such as resonant frequency' to be adjusted simply by varying the thickness of said at least one spacer.

The at least one spacer preferably has a small area compared to the area of the loop, preferably no more than 10% of the area of the loop, and preferably is not positioned adjacent a voltage maximum point of the loop.

As an alternative to the above argument, a substantially continuous sheet of dielectric of lower permittivity than the substrate of the uppermost board may be used as a spacer, the thickness of the spacer being selected as required. For example the uppermost

circuit board may have a glass fibre substrate, and the sheet may be formed from PTFE or polyamide. This arrangement, which does not require air between the boards, may produce a more rigid antenna.

As mentioned above, the antenna may be formed on a printed circuit board. In addition to substantially rigid substrates, such as glass-fibre or SRBP, a flexible substrate, such as acetate or polyethylene may be used. Such boards are commonly referred to in the art as "flexi-boards", and the term printed circuit board, as used in this specification, is intended to encompass all such variants; the essential requirement is that the board comprises a conductive (e.g. metallised) track on an insulating substrate.

If the printed circuit board is flexible, it may be more readily mounted on a surface which possess a degree of curvature, such as a vehicle windscreen.

In a development of the invention, a further loop may be spaced below the ground plane. The further loop preferably incorporates a resistance, of typically less than 100 Ω. This can increase the ratio of the signal given above the ground plane to the signal given below the ground plane. This development of the invention incorporating a loop below the ground plane may be formed on a multi-layer printed circuit board, or on a plurality of spaced boards.

Antenna devices according to the present invention may be used over a very wide range of frequencies, by selecting the dimensions appropriately for the frequency employed. However, the antenna

device is preferably employed at frequencies above 100 MHz up to several tens of GHz. Particularly, it may be used at frequencies of around 800-1200 MHz, as used in mobile telephone systems. At such frequencies, the loop may be formed on a first printed circuit board of about 2 mm thickness or less, spaced about 2 mm from a second circuit board forming the ground plane, the assembly being about 6 mm thick or less and having sides of about 6 cm or less, to produce a very compact antenna.

Another advantage the present invention provides is that a substantially vertically polarised signal can be generated from a horizontally mounted planar antenna device. The radiation pattern of the horizontally mounted device can be likened to that of a vertically mounted half-wave dipole.

Previously, it has been necessary to have a vertically protruding antenna in order to produce a vertically-polarised signal. This has many disadvantages; for example, when mounted on a vehicle, a protruding aerial is conspicuous, causes aerodynamic drag, and is prone to vandalism.

The bandwidth of the antenna can be altered by altering the thickness of the loop in a radial direction.

According to a development of the invention, additional conductive portions may be attached around the circumference of the loop. These may be positioned so as to act as tuned notch filters, to reduce the antenna efficiency at selected frequencies,

or to tune the antenna to a particular transmission line.

The antenna device may be coupled to known transmission lines, in a variety of ways, a preferable method being to connect an unbalanced coaxial line directly to the two connection points, with the outer ground connector also connected to the ground plane. Alternatively, a balanced line may simply be connected to the two connection points (neither of the connection points being connected directly to the ground plane). As further alternatives, other known means of feeding an antenna may be used, in particular capacitors and/or inductors may be used to couple the antenna device to a transmission line of a given impedance.

A preferred arrangement for coupling the antenna device to a (coaxial) line is to provide a substantially arcuate conductor stub in the plane of the loop, outside and substantially parallel to a portion of the loop, said conductor stub having a connection point along its length joined to a first connection point of the loop and to the ground plane, the outer conductor of the coaxial line being connected to an end of said conductor stub, and the centre conductor of said coaxial line being connected to the second connection point of the loop.

The length and thickness of said conductor stub, its spacing from the loop, and the point of joining to the loop are selected to give the desired impedance and capacitance to match the loop to the coaxial line at a desired frequency. In addition, the length of exposed

central conductor of the transmission line is adjusted to provide a desired reactance for matching the transmission line to the loop. The positions of the connection points around the loop are also varied to obtain the desired impedance and resonant frequency.

With this arrangement, the connection points are preferably spaced 60°-120° apart. More preferably the connection points are approximately 90° apart, typically being spaced 70°-110° apart. This may make the characteristics of the loop relatively insensitive to manufacturing tolerances in positioning of the connection points.

The effective electrical length of the loop may be altered (shortened) by forming a short circuit from a point on the loop to a portion of the conductor stub.

If the loop is formed on a printed circuit board, the conductor stub may advantageously be formed on the same board.

Advantageously, the transmission line (e.g. coaxial cable) is connected (e.g. soldered) directly to the surface of the loop. This avoids the need for extra conductive portions around the loop which may alter its characteristics, and allows the position of the connection points to be adjusted relatively easily.

According to a development of the invention, means can be provided for varying the length of the electrically conductive loop. Typically, this can be achieved by providing a non-closed loop, in which each end is connected to a joining portion comprising a conductive part. The two conductive parts, optionally

substantially parallel, may be joined at any of a number of places along their length, so that the total length of conductive loop is varied.

Generally, the resistance of the electrically conductive closed loop is made low, typically less than 1 Ω. This reduces resistance losses, and increases the Q factor of the antenna. However, according to another development, the resistance of the loop can be increased, typically by inserting a resistor (of typically from 300 Ω - 600 Ω) in the loop at a joining portion, to produce a wide band antenna device, having a low Q.

According to a further development of the invention, one or more conductive loops which are either greater in circumference, or (more typically) smaller in circumference than the loop of the basic antenna device may be employed. These may be co-planar with the basic antenna loop (if that loop is itself planar), or may be located above the basic loop, or more typically between the basic loop and the ground plane. These can act to alter the directional pattern of the radiation, and can be used to achieve greater gain or directivity.

Preferably, where the basic antenna device is formed as a loop on a printed circuit board, the additional loop or loops may be formed on the same surface as the basic antenna loop.

According to another aspect of the invention, one or more capacitors can be inserted in the loop (connected in series). This allows a wider bandwidth

to be attained, and if these are inserted in a loop of irregular shape, a compact antenna device having a given directional pattern can be achieved. Typically, in an antenna device for use with signals of the frequencies employed in mobile telephones, the capacitor, or capacitors will each have capacitance in the range of about 0.03-14 pF.

According to yet another aspect of the present invention, the antenna device of the present invention may be used to drive other antenna array systems which are otherwise difficult to couple to a standard transmission line.

The antenna device of the present invention may be used in phased arrays, or in passive arrays.

The present invention also provides a mobile telephone incorporating such an antenna device. The antenna device can be mounted so that the ground-plane is between the user and the loop. In this way, the user may be shielded from the radiation by the ground plane, with the overall size remaining very small. It has been suggested that radiation from mobile telephone antennae can have disadvantageous effects on a user, but it has not hitherto been possible to provide a small efficient antenna device for a mobile telephone which enables the user to be shielded.

Embodiments of the present invention will now be described, by way of example, with reference to the following drawings in which:

Figs. 1a-1c illustrate examples of prior art antennae;

Fig. 2 is a schematic diagram of a first embodiment of the present invention;

Fig. 3 is a plan view of a preferred embodiment of the present invention;

Fig. 4 is a side view of the embodiment of Fig. 3;

Fig. 5 shows schematically alternative ways of coupling an antenna device of the present invention to transmission lines;

Fig. 6 shows schematically an alternative embodiment;

Fig. 7 shows schematically developments of the invention in which distortion rings are present to alter the field pattern;

Fig. 8 shows approximate plots of field patterns obtained in the present invention;

Figs. 9a and 9b are polar plots showing radiation patterns obtained with the embodiment of Figs. 3 and 4; and

Figs. 10a and 10b are comparative polar plots showing polar plots obtained with the conventional antenna of Fig. 1c.

As shown in Fig. 2 an embodiment of the present invention comprises a loop 1, typically circular, spaced above a ground plane 2 by a dielectric 3. The loop 1 is conductive, and is typically made of copper. The ground plane 2 is also conductive, and is also typically made of copper. The ground plane 2 is preferably formed as a continuous conductive sheet, but, for example, a mesh, or other arrangement may be

used. Differing arrangements of ground planes are well known in the art.

The antenna device is typically coupled to a coaxial transmission line 5. The central conductor 6 of the coaxial cable 5 is connected to the loop at a connection point 10, and the outer conductive sheath 7 is connected to the loop at a second connection point 11 spaced apart from the first connection point 10 by an angle α. The angle α is typically 45°. The second connection point 11 is also connected to the ground plane 2. The coaxial cable has an outer insulating sheath 8, and an inner dielectric sheath 9 between the central conductor 6 and outer conductive sheath 7.

The dielectric material may be, for example, PTFE, glass fibre board, SRBP, ABS plastics, ceramics, or other suitable materials. It is also possible for the space between the conductive loop and the ground plane to contain air. However, the dimensions may be reduced, and the maximum power transmitted increased if a suitable dielectric is chosen.

At higher frequencies, e.g. above 1 GHz, dielectric losses can become significant, and the material of the dielectric needs to be selected appropriately. It has been found that PTFE and ceramics materials are particularly suitable for use at higher frequencies, e.g. around 2 GHz.

The thickness of the ground plane should be sufficient to ensure low resistivity, to minimise resistive losses. It is desirable to keep the conductor thickness small to reduce weight, and because at high

frequencies the current flows mainly near the surface of the conductor. Preferably, the thickness is less than 1cm, and more typically it is less than 1mm, e.g. formed as a conductive copper (or silver or gold) layer on a printed circuit board.

Referring to Figs. 3 and 4, a preferred embodiment for use in mobile telephone communications at a frequency of approximately 800 MHz is described. In this embodiment, printed circuit boards are used to form the loop and ground plane: the loop 1 is formed on a printed circuit board substrate 3a which is spaced above the ground plane 2 comprising a conductive copper sheet on a circuit board substrate to leaving an air gap 3b. The air gap 3b is maintained by spacers 13a,13b sandwiched between the substrate 3a and the ground plane 2.

The assembly is held together by a suitable known fixing means, such as adhesive (e.g. cyano-acrylate) or external clips. It is important that the fixing means does not affect the characteristics of the antenna, or that any effect is compensated for. For example, adhesive may affect the dielectric properties, or may contain moisture which is conductive. Likewise, use of conductive clips may alter the antenna characteristics significantly.

As can most clearly be seen from Fig. 3, an arcuate conductive stub 15,19 is formed from a piece of track substantially parallel to a portion of the loop 1, and joined to the loop 1 at a connection point 11 by a joining portion 16. A joint 17, which may comprise

the same material as the conductive sheath 7 of the coaxial cable 5, is soldered to the conductive stub 15,19 and to the ground plane 2. The central conductor 6 of the coaxial cable 5 is soldered to the loop 1 at a connection point 10. The outer conductive sheath 7 of the cable 5 is soldered to a portion 15 of the conductive stub 15,19. The other portion 19 of the stub 15,19 is shaped so as to match the cable to the loop at the desired resonant frequency.

The side of the antenna to which the transmission line is coupled may be varied, for example if an array of antennae, as described below, is employed. Referring to the orientation of the antenna shown in Fig. 3, a second antenna may be mounted to the right of the antenna shown with its coaxial cable connected, mirror-fashion, to the left of the loop.

Matching is carried out experimentally. The loop 1 is slightly smaller than would be required if the transmission line were connected directly to the connection points, which gives the loop a slight (capacitative) reactance at the resonant frequency. The length of the arm 19 is then adjusted experimentally to obtain the optimum (inductive) reactance, so that the currents flowing in the loop are substantially symmetrical, and maximum radiated field is obtained for a given input signal.

For use at approximately 850 MHz, a loop radius of about 19 mm was used, with a copper track width of 1.5 mm. The stub portion 15,19 had an overall length l of about 32 mm, formed from an arcuate portion of track

having a width of 4 mm and a radius of curvature S of approximately 23 mm. The width j of the joining portion 16 was 5 mm. The overall width w of the substrate 3a was 45 mm, and the overall height h was 51 mm approximate with the spacings a and b of the edge of the loop from the edge of the substrate being approximately 2 mm. This was mounted on a ground plane 2 approximately 5 cm wide by 6 cm tall.

The portion of central conductor 6 of the coaxial cable 5 exposed outside the outer sheath 7 was approximately 15 mm long. This length was selected to give best matching of the cable 5 to the antenna. With this arrangement it was found that it was not necessary to couple the central conductor 6 to the connection point 10 via a capacitor as in a conventional γ match arrangement.

The substrate 3a was glass fibre circuit board, having a relative permittivity of 5.4, approximately 1.2 mm thick. The spacers 13a,13b were formed from strips of glass fibre board. To adjust the resonant frequency, for example to resonate in a different band, the thickness of the spacers 13a,13b was altered by a small amount. For use at 835 MHz, each spacer has a thickness of approximately 1.08 mm, and for 910 MHz, each spacer was 1.30 mm thick.

Thus in this embodiment, a small increase in the spacing of the ground plane and loop caused an increase in resonant frequency.

All of the above parameters were determined experimentally by trial and error. It was found that

parameters such as impedance and resonant frequency were relatively insensitive to small variations (± 5 mm or so) in the location of the connection point 10 or of the length of the portion 15 of the conductive stub 15,19. This permits variation due to manufacturing tolerances to be accommodated. It was found that the dimensions of the portion 19 of the conductive stub 15,19 are relatively critical in determining resonant frequency and eliminating spurious resonances.

As the angle α is reduced, the efficiency tends to drop, and as α is increased, the usable bandwidth is found to decrease. Experimentally 90° is found to be optimum with the above dimensions, and a 50 Ω coaxial cable.

It was possible to shorten the effective electrical size of the antenna by short-circuiting a point on the conductive stub 19 to a point on the loop 1. Preferably said point on the loop 1 is substantially adjacent said point on the conductive stub 19 to which it is short-circuited. For example, in the embodiment depicted in Fig. 3, said points are located respectively on the loop 1 and on the conductive stub 19, each being a few mm to the left of the joining portion 16.

Figs. 9 and 10, described below, show typical results obtained with the above embodiment and with a conventional antenna, in which the conventional antenna was driven at a higher power.

For use at lower frequencies, a larger loop is used, and for use at higher frequencies, a smaller loop

is used. In general, the loop circumference is typically a little over one-half of the effective wavelength employed, up to about three-quarters of the wavelength employed. However, the precise size will depend on the dielectric used and the matching arrangement, and may be determined by trial and error. As can be seen from the above embodiment, the circumference of the loop may be approximately one third of the free space wavelength.

It is generally found that the impedance increases as the angle α between the connection points 10,11 increases. As the angle α becomes small, the efficiency tends to drop, the antenna behaving like a short circuit.

Increasing the spacing between the conductive loop 1 and the ground plane 2 is found to decrease the impedance of the antenna, and generally tends to decrease the resonant frequency. However, with certain arrangements, an opposite effect is obtained.

Increasing the loop 1 circumference is found to decrease the resonant frequency, but does not substantially affect the impedance if the same relative proportions are maintained.

Inserting a dielectric 3,3a,3b having a higher relative permittivity between the loop and the ground plane tends to decrease the impedance, and also to decrease the resonant frequency.

The bandwidth is dependent on the above parameters, which are selected in combination to obtain a desired value.

Thus, the spacing of the connection points 10,11, the spacing of the loop 1 and the ground plane 7, the dielectric material 3,3a,3b, and the overall circumference of the loop 1 may be altered to achieve a desired impedance and resonant frequency. The parameters are adjusted empirically while measuring voltage standing wave ratio while transmitting a signal of the desired frequency, and monitoring transmitted field strength until desired characteristics are obtained, following the above general rules.

It has been found that attaching an extra conductive portion to the loop, so that the loop is not symmetrical alters the properties of the antenna. For example, it can cause the loop to reject certain frequencies, and behave as a crude notch filter.

Although the antenna is preferably planar, it may be formed as a flexible structure, for example comprising one or more flexible circuit boards. It is found that mounting the antenna with a slight degree of curvature, such as that typical of a vehicle windscreen, does not substantially affect its characteristics. Thus an antenna for a vehicle windscreen may be formed as a flexible, preferably self-adhesive, "sticker".

When mounted in a vehicle, it is found that an array of antennae, typically 2 or 4, may give better results than a single antenna. The antennae may share a common ground plane 2, and the array is typically substantially planar, although it may be flexible as described above. The antennae may be co-linear, the

array forming a strip. Many arrangements of signal combiners/dividers are known in the art for coupling a plurality of antennae to a single transmission line. A preferred arrangement of power dividing means which results in a compact antenna is to provide a strip line mounted above a ground plane, the strip line being electrically one half of the wavelength employed. Two antennae, or further combiners in the case of more than two antennae, are coupled one to each end of the strip line, and the transmission line is connected to the centre. If this arrangement is employed, the strip line may utilise the same ground plane 2 as the antennae.

In particular, the ground plane 2 may be formed as one side of a double-sided circuit board, the strip line being formed on the other side. Coaxial cable may be attached to the ends of the strip line, and connected to the antennae as described previously. Alternatively through-hole plating may be employed, the antenna array being formed as a multi-layer sandwich comprising (sequentially) loop, ground plane, strip line, with a through connection from the loop to the strip line. This may result in a very compact arrangement. However it is found that this arrangement requires a fair degree of trial and error to obtain the best results as the antenna characteristics can be affected by mutual coupling, and coupling to the power dividing means. As an alternative which is slightly less compact, but which may be simpler to align, the strip line may be formed

as a separate double-sided board mounted below the antennae ground plane, the strip line facing away from the antennae.

When an array of antennae is employed, the orientations and/or phases of the individual antennae may be chosen to provide a desired polarization pattern, e.g. a quasi circular polarisation. The desired pattern is obtained by trial and error, in accordance with known techniques for driving phased arrays of antennae.

As shown schematically in Fig. 5a, an antenna device of the present invention can be coupled to a balanced transmission line 26,27. The two wires 26,27 of the transmission line are connected via respective capacitors 28,29 to connection points 10,11 spaced around the loop. Each capacitor is chosen to match the impedance of the transmission line to that of the antenna using standard techniques. As discussed above, the impedance of the antenna itself can be altered to simplify matching to a transmission line of a given impedance. The capacitors would be of the order of about 10 pF for frequencies of the order of about 1 GHz. The loop can be connected to the ground plane 2 at a voltage minimum point by a connector 20.

As shown in Fig. 5b a γ feed may be employed, in which the central conductor 6 of a coaxial cable 5 is coupled to a connection point 10 on the loop 1 via a capacitor 24. The sheath 7 is connected to the ground plane 2, as is a further connection point 11 on the loop 1.

Alternatively, as shown schematically in Fig. 5c, an ω feed may be employed, in which the central conductor 6 of a coaxial cable 5 is coupled to the connection point 10 on the loop 1 via a capacitor 24, and also to the grounded connection point 11 on the ring via a further capacitor 25.

Other known means of feeding antennae may be employed. In a development of the invention, as shown schematically in Fig. 6, a conductive loop 1 is formed having two parallel inwardly extending portions 21,22. These are bridged by a connection portion 23 at a predetermined point along their length. The advantage of this arrangement is that the location of the connection point 23 can be varied relatively easily. For example, the loop 1 and inwardly extending portions 21,22 may be formed as copper tracks on a printed circuit board, and the connection portion 23 may be formed as a bridge after manufacturing the printed circuit board. The antenna may be coupled to a transmission line by any of the methods previously discussed.

As a further alternative, the connection portion 23 shown in Fig. 6 may be replaced by a resistance, typically having a resistance of 300 Ω-600 Ω to give a relatively wide band aerial. It is found that the resistance of the loop is increased, the resonance becomes less sharp. It is also necessary to re-adjust the impedance of the loop, e.g. by varying the circumferential spacing of the connection points 10,11.

As shown schematically in Fig. 7a a distortion ring 30 may be included inside the antenna loop 1, to

alter the field pattern of the antenna. There may be one or several rings 30, and these may be located inside, or outside the antenna loop 1.

In the development shown schematically in Fig. 7b, the distortion ring 30 may be formed as a loop having parallel inwardly extending portions 31,32 joined by a bridge 33. Thus, in a similar way to the embodiment shown in Fig. 4, the overall length of the distortion rings may be altered. Importantly, a resistance may be used as the bridge 33 completing the loop 30.

Fig. 8a is a sketch giving an indication of the polar diagram obtained from a single loop antenna device of the present invention. Axis 55 represents distance in a radial direction, and axis 56 represents vertical distance, with the ground plane horizontal, and the centre of the loop lying at the intersection of the axes. As can be seen, the curve 50, which is an approximate half power envelope, has a similar shape to that obtained from a half-wave vertical dipole.

In Fig. 8b, the curve 50 obtained from a simple single-loop antenna device of the present invention is shown on the same axes as the curve 51 obtained for an antenna device having an inner distortion ring, as shown in Fig. 7a.

In a development of the present invention, a loop, similar to that illustrated in Fig. 6 may be employed, in which the connection portion 23 is substituted by a capacitor. There may be one or more capacitors located around the loop. This results in a

wide band antenna, whose characteristics may be altered by adjusting the value of the capacitor(s) and/or the length of the intervening connection portions.

In use, it has been found that the results obtained with an antenna device of the present invention are generally better than those obtained with a helical wound aerial, as illustrated in Fig. 1c, as conventionally used in mobile telephones. It was found that in places where it was not possible to obtain satisfactory operation of a mobile telephone using a conventional aerial, reception was made possible by substituting the conventional aerial with an antenna device of the present invention.

Furthermore, the antenna radiates preferentially in a direction away from the ground plane. This allows the antenna to be fitted to a mobile telephone so that in use, the preferred direction of radiation is away from the body, as demonstrated by the results obtained:

Fig. 9a shows the radiation pattern obtained from the above described embodiment of Figs. 3 and 4 when vertically mounted and fed with a signal of -15.8 dBm at 840 MHz. The centre of the graph corresponds to a field strength of -30 dBμV/m, measured at 3m from the antenna, and each consecutive outer ring corresponds to 5 dB greater signal strength than the previous ring.

Fig. 9b shows the corresponding pattern obtained with the same antenna mounted on a Motorola ™ "Flip phone".

Figs. 10a and 10b show the corresponding results obtained with a conventional helical antenna when fed

with a stronger signal of -7.6 dBm.

As will be appreciated, the antenna of the present invention can be put to a variety of uses, the characteristics being chosen for each particular application in accordance with the general teachings of the above description.

CLAIMS

1. An antenna comprising an electrically conductive closed loop spaced above a ground plane, the loop having first and second connection points spaced around the loop for coupling the loop to a transmission line.

2. An antenna according to claim 1 wherein the loop is substantially planar, the plane of the loop being parallel to the ground plane.

3. An antenna according to claim 2 wherein at least the loop is formed on a printed circuit board.

4. An antenna according to claim 3 wherein said printed circuit board is rigid.

5. An antenna according to any one of claims 1-3 wherein a first dielectric layer having a higher relative permittivity than air is provided between the loop and the ground plane.

6. An antenna according to claim 5 wherein a second dielectric layer or an air space having a lower relative permittivity than said first dielectric layer is provided between the loop and the ground plane.

7. An antenna according to claim 6 wherein the first dielectric layer is adjacent the loop and the second dielectric layer or air space is adjacent the ground

plane.

8. An antenna according to any one of the preceding claims wherein one of said first and second connection points is connected to the ground plane.

9. An antenna according to any one of the preceding claims comprising a further conductive portion connected to the loop.

10. An antenna according to claim 9 wherein said further conductive portion is connected to one of said first and second connection points.

11. An antenna according to claim 10 arranged for connection to a coaxial transmission line having a central conductor and an outer conductor, wherein the first connection point is arranged for connection to said central conductor, and said further conductive portion comprises a strip adjacent to the outside of a portion of the loop, said strip comprising a first arm portion arranged for connection to said outer conductor of the transmission line, a second arm portion arranged to provide a reactance to match said transmission line to the loop, and a joining portion, connected to the second connection point of the loop and to the ground plane, joining said first and second arm portions.

12. An antenna according to any one of the preceding claims wherein said first and second connection points

are spaced between 30° and 150° apart around the loop.

13. An antenna according to claim 12 wherein said connection points are spaced between 60° and 120° apart.

14. An antenna according to any one of the preceding claims adapted for use at frequencing above 600 MHz, wherein the diameter of the loop is 8cm or less.

15. An antenna according to any one of the preceding claims adapted and arranged for use in mobile telephone communications.

16. An antenna according to any one of claims 1 to 3 or 5 to 15, wherein the antenna is flexible.

17. An antenna according to any one of the preceding claims adapted and arranged for mounting on a vehicle windscreen.

18 An antenna array comprising a plurality of antennae according to any one of the preceding claims.

19. An antenna array according to claim 18 comprising combining means for coupling at least two of said plurality of antennae to a single transmission line.

20. An antenna array according to claim 18 wherein said combing means comprises a conductive strip spaced

below said ground plane.

21. A mobile telephone comprising an antenna according to any one of claims 1 to 16.

22. A mobile telephone according to claim 21 arranged so that in use the ground plane of the antenna is positioned between the loop and the user of the mobile telephone.

23. Use of an antenna according to any one of claims 1 to 17 in mobile telephone communications.

24. An antenna comprising an electrically conductive substantially closed loop spaced above a ground plane, the loop having first and second connection points spaced around the loop for connection to a transmission line, the loop having at least one discontinuity at which a capacitor is connected in series with the remainder of the loop.

25. An antenna according to claim 24 in which at least one of said first and second connection points is spaced away from said discontinuity around the circumference of the loop.

26. An antenna substantially as any one herein described, with reference to Figs. 2-7 of the accompanying drawings.

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Patents Act 1977 L .miner's report to the Comptroller under Section 17 (The Search report)	Application number GB 9509022.1
Relevant Technical Fields (i) UK Cl (Ed.N) H1Q (QKA, QDA, QDC, QDE, QDH, QDW, QDX) (ii) Int Cl (Ed.6) H01Q (1/24, 1/27, 1/32, 1/38, 7/00, 7/04)	Search Examiner J A WATT Date of completion of Search 1 AUGUST 1995
Databases (see below) (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii) ONLINE: WPI	Documents considered relevant following a search in respect of Claims :- 1-26

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Category	Identity of document and relevant passages		Relevant to claim(s)
P,X	GB 2276274 A	(SEIKO EPSON) Figure 16	1 at least
X	GB 2217112 A	(MATSUSHITA) Figures 11, 12 and 24 to 26 and line 25, page 23 to line 16, page 25	1 and 24 at least
X	GB 2168538 A	(BBC) Figure 1 and lines 78 to 98, page 1	1 and 24 at least
X	GB 0926173 A	(GSV) whole document	1 and 24 at least
X	EP 0516303 A1	(Figures 16 and 17 and lines 50 to 58, page 5	1 and 24 at least

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